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# AERODYNAMIC PROBLEMS OF STOL AIRCRAFT

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# AERODYNAMIC PROBLEMS OF STOL AIRCRAFT *

R. J. Ceresuela **

The desire of reducing the duration of aircraft flights /44***
has led to a research effort involving the concept of short takeoff and landing aircraft (STOL). These aircraft are capable of discharging and accepting passengers in the immediate vicinity of cities.

The STOL is characterized by high lift, which means that the aerodynamicist must combine both aerodynamic problems and structural and propulsion problems. Also it is necessary to consider new conditions of acceptability for the population on the ground.

A number of specific aerodynamic problems are involved and a discussion will deal with some of them.

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* Lecture presented on October 10, 1972 in Vienna, Austria at the Second International Student Conference of the International Astronautical Congress. The translation from English to French was performed by B. Debout, Armament Engineer. (The English slides shown at the lecture are reproduced here.) The initial English version will appear in the Astro Student Review of the AIAA.

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*** Numbers in the margin indicate pagination of original foreign text.

For several years, efforts to reduce the air times have led to the realization that an ever-increasing part of the "door to door" time of a trip included ground transportation at the departure and arrival points as well as waiting times at the airports. From this, the idea of locating small airports in the immediate vicinity of the main cities evolved. Also the development of V/STOL vehicles began to evolve. Numerous prototypes were constructed and a summary is given in [1].

A number of factors have delayed the realization of such systems up to a few years ago. First of all, the voluminous V/STOL generation developed in the past exclusively contained only two types of aircraft:

- aircraft with vertical thrust, for which the propulsion systems and the motors, or even the entire wing, were rotated for the cruise flight.

- aircraft with jet deflectors.

These aircraft were all noisy and not very economical.* From the point of view of economy, and independent of the development costs associated with such complex machines, it should be noted that all aircraft which can perform stationary flight will have characteristics in between the following two extreme cases.

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* The Breguet 941, which is at present flying in the United States with the designation Mac Donnell Douglas 188, is at present being developed for STOL operations. Also future guidelines are being developed on the basis of this aircraft. It seems that this aircraft will not satisfy them for two reasons. Its development is limited to the velocity specifications of the new STOl generation $M_{max} > 0.7$. This was made possible by the development of supercritical profile wings.

The first case is the helicopter, which can fly for one hour with a total weight of 10,000 pounds and which will consume 500 pounds of fuel [2]. The other extreme is the pure turbojet which consumes approximately its weight in fuel during a flight of this duration. Those of us who have carried out tests with such machines know about their noisy characteristics and the delicate pilot functions. Because of their flight characteristics, they are almost impossible to fly, as a large number of failures has shown.

The general feeling at the present time regarding the development of convertible type V/STOL aircraft is that it will be done in the next decade. This is true at least for civilian applications. However, because of the recent progress in large dilution motors which offer important possibilities for the distribution of air for high lift configurations and because of the improvements in the noise characteristics associated with these high rates of dilution, we believe that now more than ever it is possible to again consider short takeoff and landing aircraft.

## Noise

In order to place the aerodynamic problems associated with STOL aircraft in perspective, it is appropriate to briefly recall the noise situation. During the 50's, the first appearance of jets made it necessary to define a scale which connected the new noise levels, measured in dB to the human annoyance levels: this was called PNdB or the "Perceived Noise Unit".

At the beginning of the 60's the number of jet aircraft increased. Also a noise exposure value was introduced, the

"Noise and Number Index". Towards the middle of the 60's, efforts were made to include any operations in the parameters used to describe the noise. Today, a universal unit used for certification purposes is the "Effective Perceived Noise Unit" (EPNdB) which relates the human response to the character (that is to the spectrum), to the duration, and to the level of the noise. How much can we tolerate? A rough answer is 115 EPNdB during the day and 105 EPNdB at night. Let us remember that 10 dB is a factor of 2. The SPAR regulation specifies a maximum EPNdB which differs according to conditions: lateral position and axial position (approach and takeoff): in each case the maximum mass depends on this value.

For the lateral noise and the noise during approach, the average values are 102 EPNdB for 300 tons, and the corresponding values for takeoff are 93 to 108. The goal is to reduce these values by between 10 and 15 EPNdB beginning in 1980 [3].

There are two reasons why the noise problem is a peculiar problem for STOL type aircraft.

- one reason is simply relocation of airports. It is predicted that the distance between the population and the aircraft could be reduced to about 500 feet at the takeoff point.

- The other reason is the fact that in contrast to classical aircraft, the approach and descent will be performed under full power, in order to provide the required high lift.

Even though the approach and takeoff inclinations will increase, the altitude gain will not suffice for completely compensating for the reduction in distance between the aircraft and the population. /45

If we examine the characteristics of various STOL projects, we can see that the final trajectories of most STOL aircraft are limited because they are not capable of developing the continuous aerodynamic forces required for deceleration down to low velocities while carrying out a rapid descent. The drag/lift ratio must be increased in order to overcome this limitation without sacrificing the lift at low velocities.

This result is a consequence of the relationship:

$$C_x/C_z = \tan(-\gamma) - \frac{dV/dt}{g\cos(-\gamma)}$$

The maximum descent angle $(-\gamma)$ is obviously obtained for $\frac{dV}{dt} = 0$ (stabilized approach)

$$(-\gamma)_{max} = \tan^{-1}(C_x/C_z)_{max}$$

This requirement is complicated because of other requirements associated with the behavior of the aircraft in the presence of gusts [4,5]. These requirements are a consequence of Chapters 21 and 25 of the F.A.R. regulations. They cannot be completely described here. However, many of them directly influence the aerodynamics. For example, for a typical 5° descent, it is necessary to have 10° incidence margins and 30% velocity margins with respect to stall conditions, for the case where one motor fails (stated otherwise, the approach velocity is 1.3 times the stall velocity, which amounts to a difference of about 20 knots). Because of the possibility of a missed landing, it is necessary to be able to reduce the descent velocity to zero using three motors at full power. The reduction in the flap settings from 50° to 40° must be enough to obtain a vertical positive velocity for a restart and a new approach. In addition, [6], a horizontal gust from the worst direction with an intensity equal to 50% of the wind velocity, or a vertical gust having an intensity of 25% of the wind velocity, should not lead to an altitude loss of more than 35 feet. Also these factors cannot bring about a change in the load factor of more than 0,30 g, nor loss of control, nor changes in the inclination angles, nor changes in the longitudinal trim angles greater than 15 and 5 degrees, respectively.

All these restrictions make it necessary to fly the "front part" of the polar, quite far away from the stall incidence and this means that it is desirable to have a high D/L ratio.

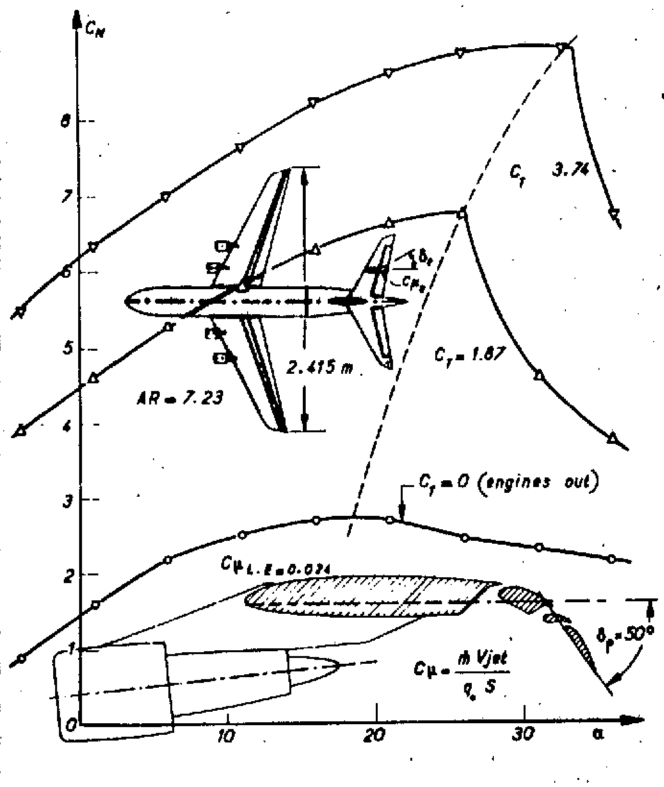
The noise and the specifications for approach have a much more noticeable influence on the aerodynamic concept of STOL aircraft than in the case for classical aircraft. This is true even for their wing and for their flap design.

## The aerodynamic problems

The lift coefficient of classical aircraft in the landing configuration is about 3. This is reduced to 1,80 to 2 because of various safety margins (gusts, etc.). Short landing requires an increase in this coefficient up to values of 4 to 5, or even more. This coefficient must be reached in the case of the failure of one engine, and for an inclination which is always zero. This amounts in fact to values of 8 or 9 which are required with four motors under full power.

Such high lift coefficients were recently made possible by the blowing capacity of motors having high dilution rates.

The STOL aircraft type being considered today is essentially a high wing aircraft (the nearness of the ground forbids a $C_z$ larger than 3), with four motors in nacelles. It has been shown that a large deflection produced in the vicinity of the




Tail on : β = 0° ; $\delta_e$ = − 50° ; $C_{\mu_e}$ = 0

[Ref: N.A.S.A. T.N.D. 6391]

Figure 1. STOL aircraft with external blowing; lift curves for various thrust coefficients.

horizontal fixed plane by the high lift of the wing brings about a horizontal instability if the thrust (and therefore the lift) is increased. Also, in all STOL aircraft projects, as well as in low approach velocity aircraft which are now flying, such as the C8A Buffalo, the elevator is preferably mounted at the top of the fixed directional plane. /46 This location improves the effectiveness of the elevator and the effectiveness of the rudder.

The general definition of a STOL aircraft for the future is as follows (Cook [7]).

- 50 to 150 passengers, a modest transport capacity for allowing high frequency service;

- 750 to 1,100 km of action radius, in order to provide relief for the shortest DC9, 727, 737 runs;

- cruise velocity of 0.7 to 0.8 Mach. This is in order to attract passengers and will be efficient for longer distances, and requires jet engine propulsion as well as supercritical wing profiles;

- wing load of 4,000 to 5,500 Pascal* for the flight quality during cruise and for the passengers' comfort;

- runway length of at least 610 meters;

- low noise level as indicated previously.

The projects essentially differ with respect to the generation of the high lift. The three candidates are:

- internal blowing at the junction point of the flaps ;

- the "dummy wing", or open blown flap;

- external blowing.

Numerous comparisons of effective costs for the three methods have been made, for example see [8]. The following comments are limited to the aerodynamic aspects.

Internal blowing

In this method, the air is sucked into the motor and a channel distributed along the span to the upper flap surface, where it accelerates the flow and brings about supercirculation. This method is the oldest one of the three. It has been tested and utilized in flights for many years in a limited way. Also it has been used to prevent the separation of the flow along the flap. The theoretical efficiencies have been reached but not enough for producing supercirculation.

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* Translator's note; 1 Pascal = 1 Newton per square meter.

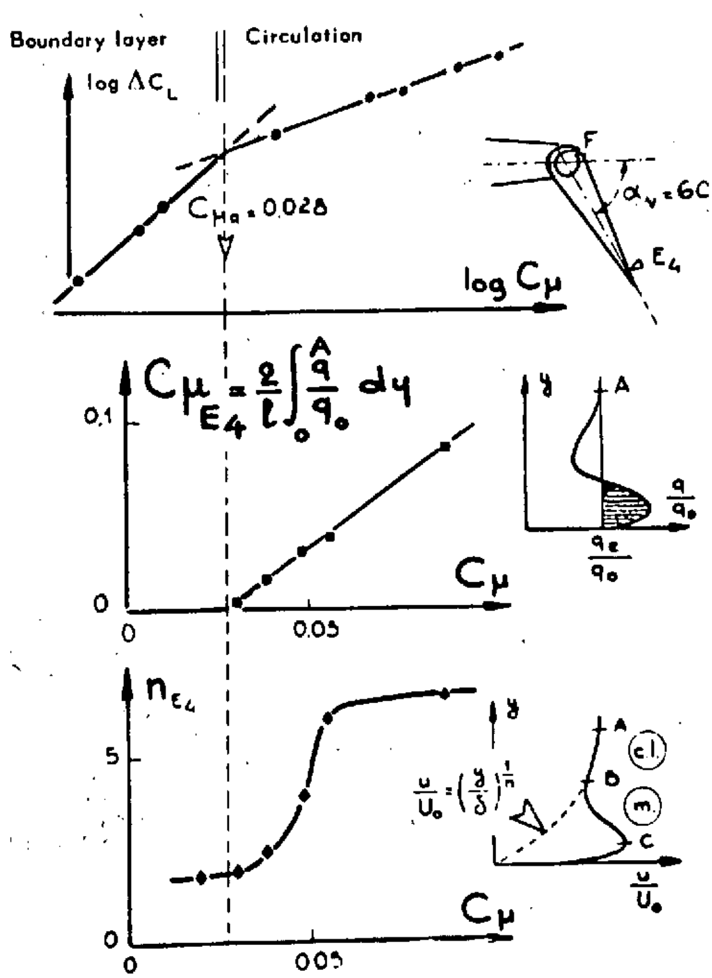


Figure 2. Reattachment criteria for the boundary layer along an extended flap.

The required blowing coefficients* are not very high, from 2% to 10% depending on the chord length and the setting of the flap. However, the lift coefficients do not go above the limiting theoretical values (a maximum of between 3 and 3.5).

These values could be acceptable for a first generation of STOL aircraft which utilize present day motors, having limited bypass capacity and with dilution rates between 2 and 4 (Beheim, [30]), present day runways and wing loads between 3,000 and 4,000 Pascal.

The theoretical problem which has not yet been resolved is the prediction of the blowing necessary for preventing separation along the flap.

A few empirical rules have been proposed for determining the magnitude of the necessary blowing.

- in reference [9], Carrière and Poisson-Quinton in 1958 showed that the curve ($C_z$, $C\mu$) has an inflection point for which $C_z$ is close to the theoretical value, and above which the real supercirculation is measured. Boundary layer studies at various points along the flap show that this condition is satisfied when the ejected sheet of air meets the boundary layer along the trailing edge and imparts an additional momentum to it which exactly compensates for its own momentum deficit. It is interesting to note that the same boundary layer studies show that for this value of blowing, the boundary layer

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* $.c\mu = \dfrac{\text{ejected momentum}}{q.A\ \text{ref.}}$

along the flap is not reestablished conforming with the velocity profile of a normal non-separated flow. On the contrary, the exponent of the usual velocity profile law remains very small (≈2) as Figure 2 shows. This fact explains why one cannot use available theoretical boundary layer results in order to solve this problem. /47

- in reference [10], Schlichting proposed in 1965 a similar criterion which also considered the momentum deficit. However, the most important thing is to calculate the boundary layer over the flap. The calculation of the high velocity ejected air sheet together with the boundary layer over the flap has become possible because of new numerical mixing methods. Basic tests must be performed in order to develop an important theoretical model. Such test programs are currently being performed in various countries. Figure 3 shows a two-dimensional test for a wing section in a low velocity wind tunnel.

The model has a chord length of 2 meters and has flaps with different curvatures, as well as blowing slots having various thicknesses. Measurements are carried out of local pressure and the boundary layer is investigated with probes. The purpose of these tests is to provide mixing profiles for the theoreticians which will be the bases of future prediction methods. Photograph A in Figure 5 shows the inverted profile which a worker is holding. Photograph B shows the flow over a flap set at 50°, with and without blowing. Various slot thicknesses must be tested, because combinations of thicknesses and ejection velocities can lead to the same attachment condition. However, there can be different noise characteristics. For example, a pressure ratio of 2.6 produced by the ventilator stage of a

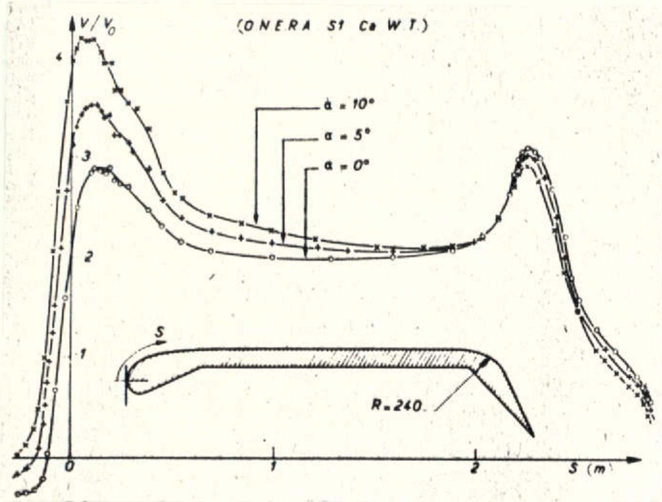



Figure 3. Two dimensional profile with tangential blowing on to extended flaps, tested in the SL wind tunnel at Cannes; calculated pressure distributions.

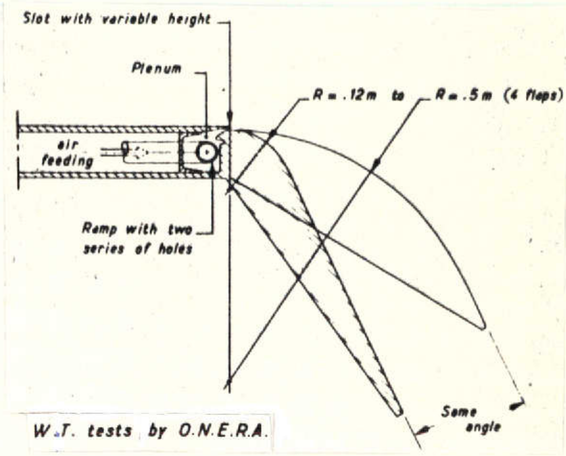



Figure 4. Tests of a 2 D profile in S1Ca; details of the blower slot.

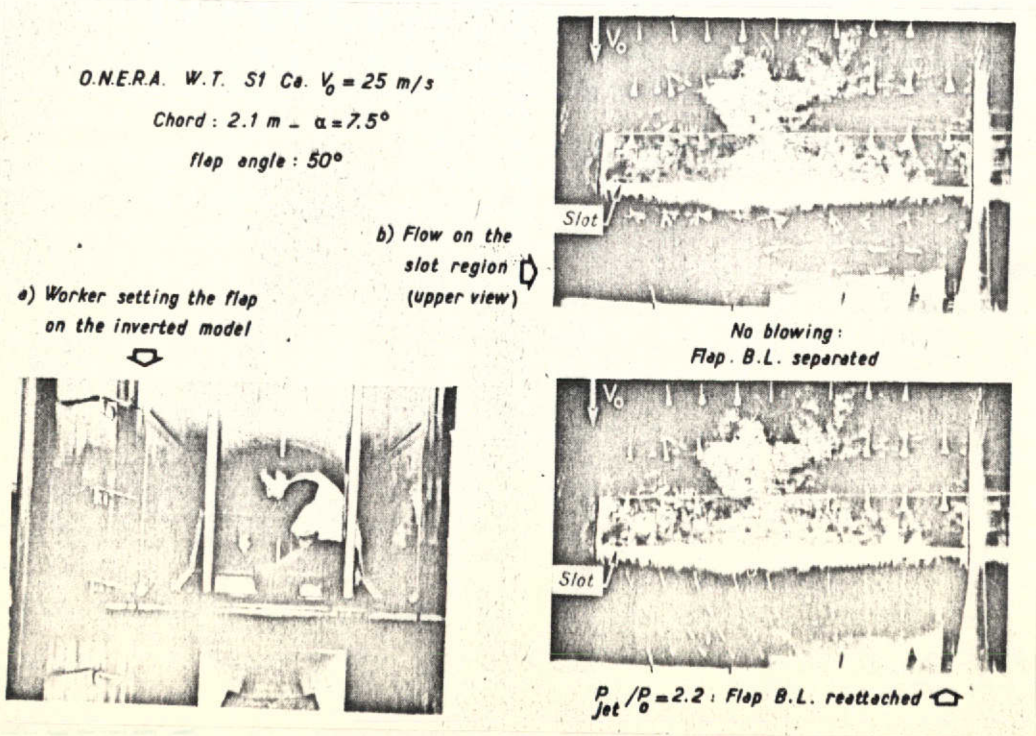



Figure 5. Tests of a 2D profile in the S1Ca; photographs of the installation and visualization of the reattachment at the flap by means of wool threads.

turbojet with a blower results in a very noisy slot.

Tests with such large models which develop increased degrees /48 of lift again impose severe problems on wind tunnel construction. The wall corrections are large and the approximate formulas must be improved. This is one of the goals of future research.

On the other hand, the large pressure gradients produced at the wall can lead to separation, and slots are required in order to reattach the boundary layer by blowing and three-dimensional effects must be taken into account.

The "augmentor wing" method

This technique (Figure 6) was described in detail in [11, 8, 12] and uses split flaps. A number of nozzles are used to blow air through the central channel in the flap. The induction effect produces a suction which sucks the boundary layer in the vicinity of the flap tip. The momentum ejected is added to the momentum of the primary jet (augmentation factor about 1.4). This is the reason for the name "augmentor wing".

This type of flap has a complex mechanical structure. The present models consist of four parts with four different kinds of kinematics. Also it is heavy and retraction during flight causes additional problems. High pressure blowers are required (at present pressure ratios above 2.6 are used), and they are also noisy. At the present time, almost full scale test programs are being carried out (Figure 7) in order to find ways of suppressing the noise. Also research is being conducted on the compromise between the high lift properties and the noise level. The complexity of this method makes it very necessary to have theoretical prediction methods of the characteristics. The development is only based on empirical research, which is quite delicate to perform and which is carried out on the test stand

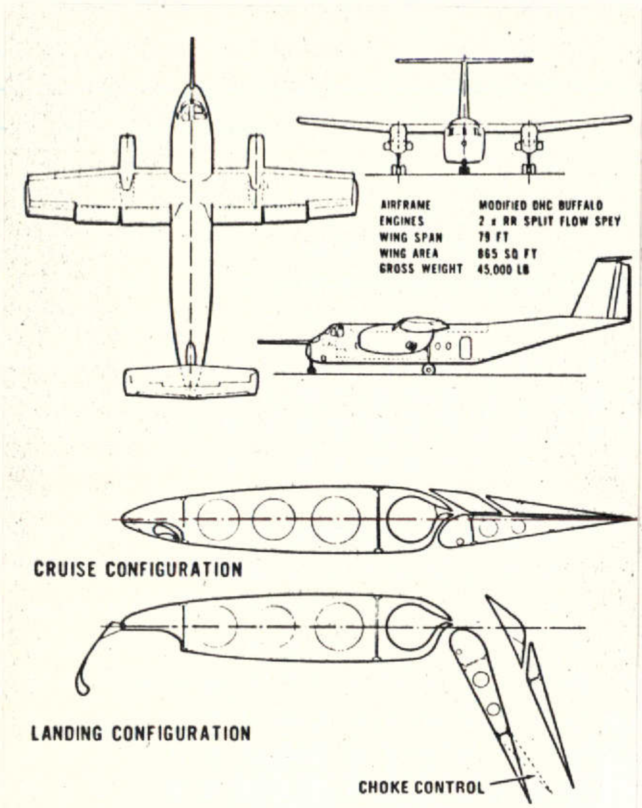



Figure 6. "Buffalo" aircraft with "augmentor wing"; details of the flap profiles in the extended and retracted positions.

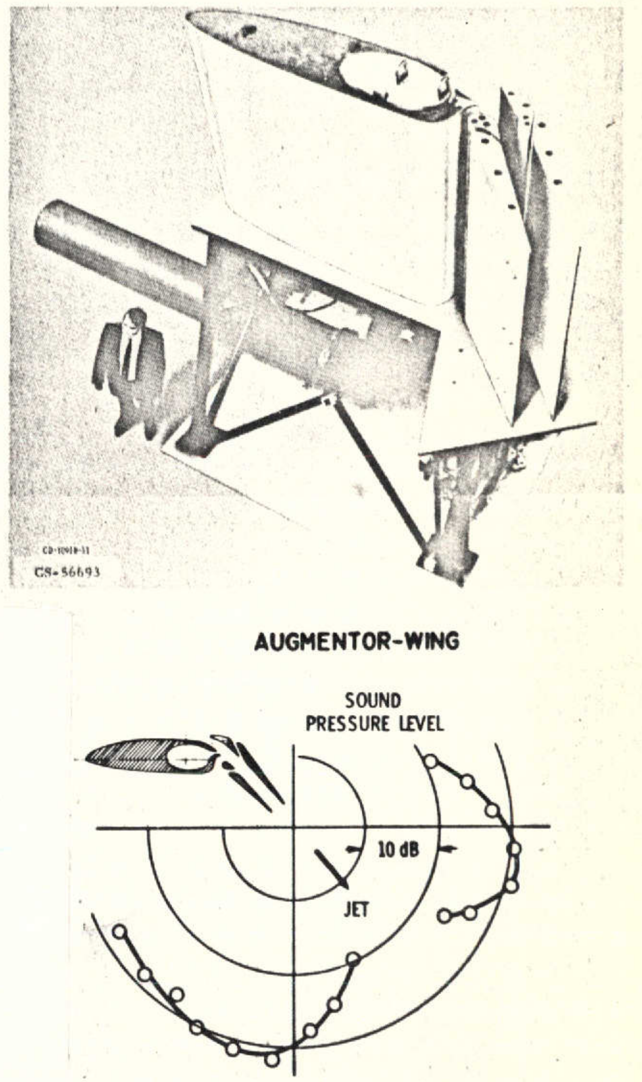



Figure 7. Installation of a dummy profile (augmentor wing) for measuring the sound.

and under flight conditions. A De Havilland C.8.A "Buffalo" was recently modified for testing this concept in flight. The turbojets were, of course, replaced with Spey motors. Therefore, it was possible to deflect part of the flux to the "augmented" flaps. Also it had articulated ejection nozzles for directing the thrust in such a way as to directly increase the lift. A complete description of this program is contained in references [13, 14]. It will be carried out over the next few years.

The NASA has been engaged in the development of two other STOL aircraft of the experimental type. These will fly in 1974. /49
It is the purpose of this program to obtain commercial STOL transport capability and tactical capability before 1980. One of these is of the "augmentor wing" type and the other is of the external blower type. Each of these has to be easily transformed, later on, to any other method of high lift, such as internal blowing, tangential blowing, which was discussed previously. The NASA program assumes that quiet motors will be available, which are being developed at the same time. The two methods of internal blowing and of the "augmentor wing" require complex interconnection of channels along the entire span, in order to solve the problem of the failure of one engine and in order to provide zero roll in spite of the loss in lift, for the case where one engine fails completely. In addition, it is absolutely necessary to install complicated flaps in the leading edge or blower slots, because hypercirculation is accompanied with overvelocities and compressions in the vicinity of the leading edge.

This merging of the propulsion system and the aerodynamic features represents one fundamental aspect of these concepts.

External blowing

Recently large dilution engines have been built together with low pressure compressors. It then becomes possible to provide lift by direct blowing on flaps containing multiple slots. Figure 8 shows one of the numerous tests in the NASA wind tunnel. The model is particularly complicated because it contains real small blowers which are to scale, as well as numerous blower channels, even at the leading edge of the elevator flap.

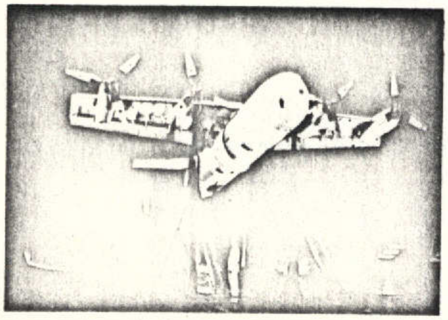
However, this method also involves serious problems:

- the high velocity airjet which hits the flap system is a noise source. Figure 9 shows a noise suppression test for measuring the spatial noise spectrum;

- the theoretical prediction of high lift produced in a given configuration cannot be predicted by theory, even for the simplest case, the two-dimensional case. This /50 is because there is no theoretical model for the circulation produced by the jet around a wing containing flaps;

- an engine failure is translated into a local loss in lift and a rolling moment which cannot be ignored and which must be controlled by differential settings of the flaps.

This safety requirement is added to the other safety margins included in the F.A. regulations which control the velocity and the incidence angles. Consequently, the maximum lift coefficients must be much higher than the values used during landing.



a) Blower model with deflected propellers (NASA Ames)

b) External blowing model (NASA Langley)

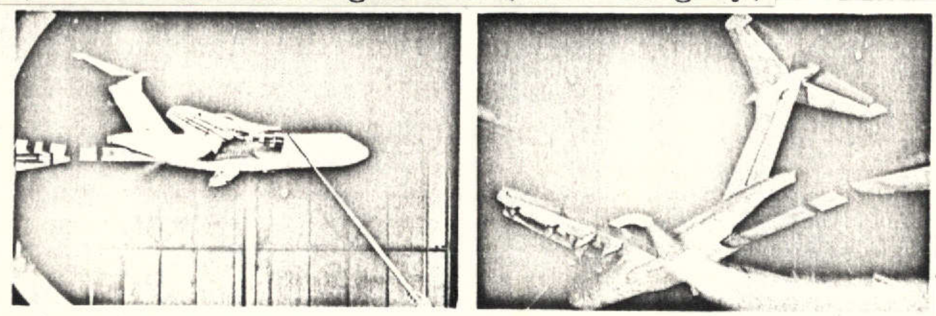


Figure 8. Large scale tests of STOL aircraft.

This problem led to numerous tests in the wind tunnels for determining the optimum configuration of the motors in order to minimize the roll problem. Figure 10 shows an example of one such research project, carried out by the O.N.E.R.A. for one-half of the body. It can be seen that the lift increase provided by the jet does not extend over the entire span. Another result (Figure 11) is that the application point of the lift resultant is displaced much less than the location of the jet. Figure 12 shows that one of the important parameters is the position of the jet impact axis with respect to the flap slots. At the present time this factor is not predictable by theory. Recently, in the United States, a proposal was made to locate the engines above the wing in order to directly blow on the top surface of the flap. However, this configuration will certainly aggravate the conditions

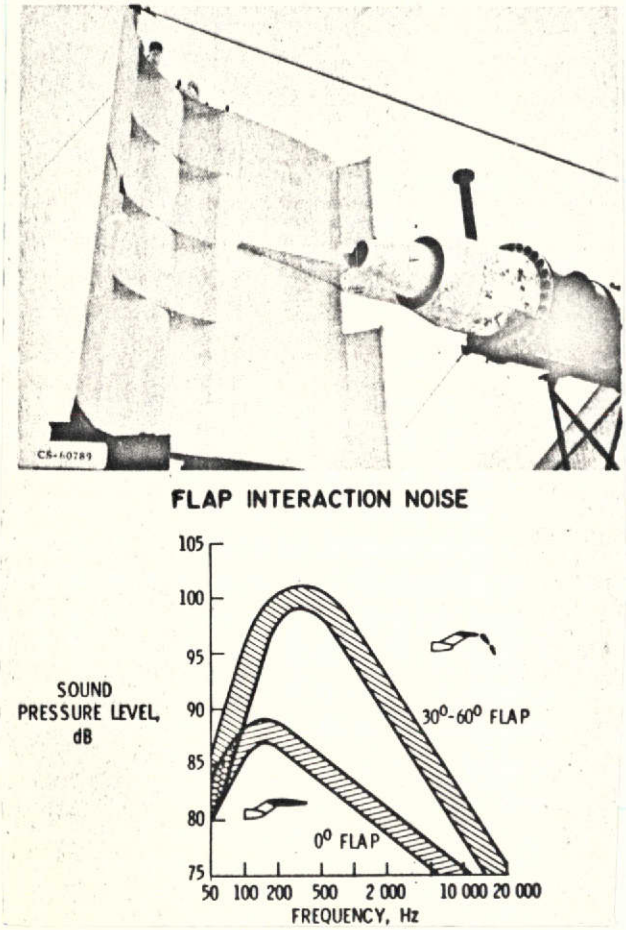



Figure 9. Mounting of a wing element with external blowing for sound measurements.

in the case of engine failure. /51

There are many of these parameters and probably there are some which have not yet been discovered.

The following have been discovered:

- The nose heaviness moments associated with the high lift are very large and require a very powerful and fast response of the elevator. In fact, there may be blowers on the elevator flap as well;

- The roll control is also important in order to provide flight safety in the case of failure of one engine. Here again, a powerful and fast response of the flaps is required. This means that specially designed flaps and control systems will have to be used, which will be able to respond to the sudden decreases in performance of one motor.

- The low descent velocities result in large fluctuations in the angle of attack and in trim angle if there are gusts. Wind tunnel tests and flight tests must include

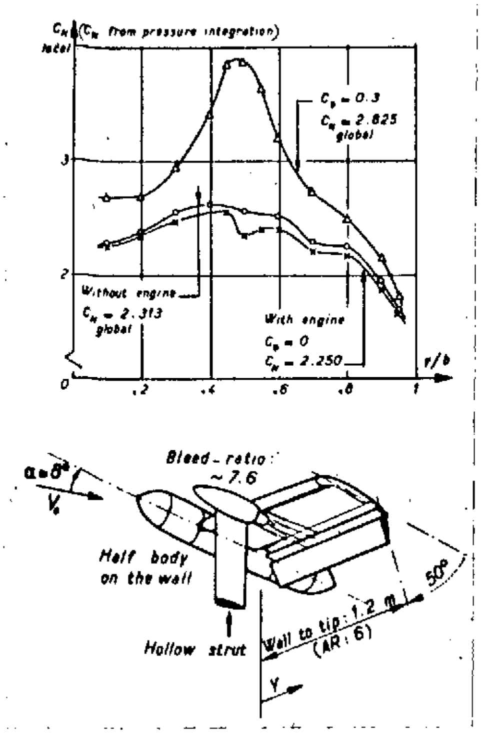



Figure 10. Studies of external blowing in the S1 Cannes wind tunnel; local lift coefficients in the span direction.

configurations which will vary these angles by 30° each, in order to make sure that the large roll angles at large incidence angles will not endanger the aircraft.

- At the present time it is realized that the noise studies carried out outside are not realistic. The O.N.E.R.A. will build a new configuration and a wind tunnel having an anechoid experimental chamber with an area of 14 x 20 $m^2$ and a length of 8.5 m. The maximum velocity will be 180 m/sec.

Transonic problems

There are many reasons for using thick wings: high lift, the space required for the retraction of complicated flaps, space for complex and interconnected channels, fuel, the requirement for lightening structure. At the present time, values of 15-17% are being considered.

The thickness and the velocity requirements $(0{,}7 \leqslant M_{cr} \leqslant 0{,}8)$ have been made compatible by the introduction of the supercritical profiles.

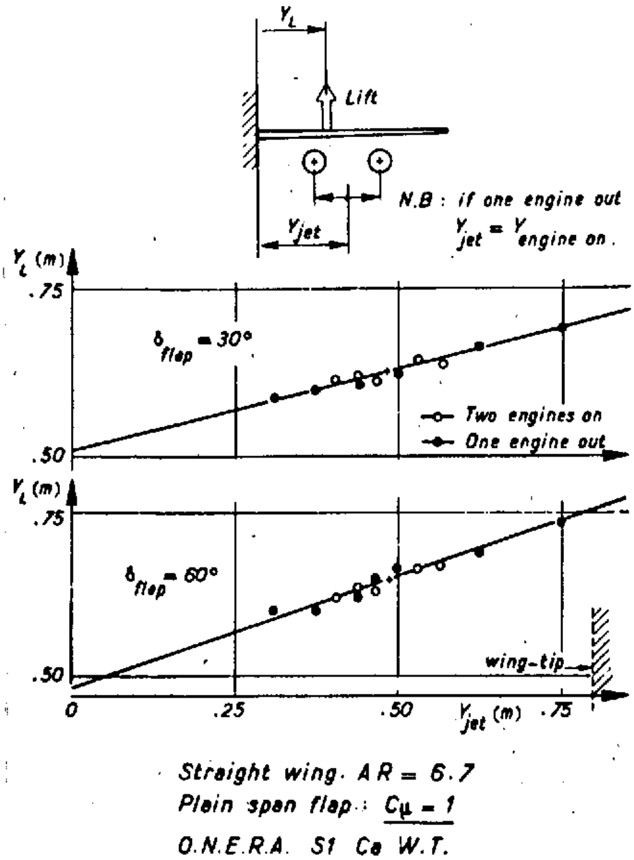



Figure 11. Spanwise position of the center of pressure, as a function of the motor position; S1 Cannes tests.

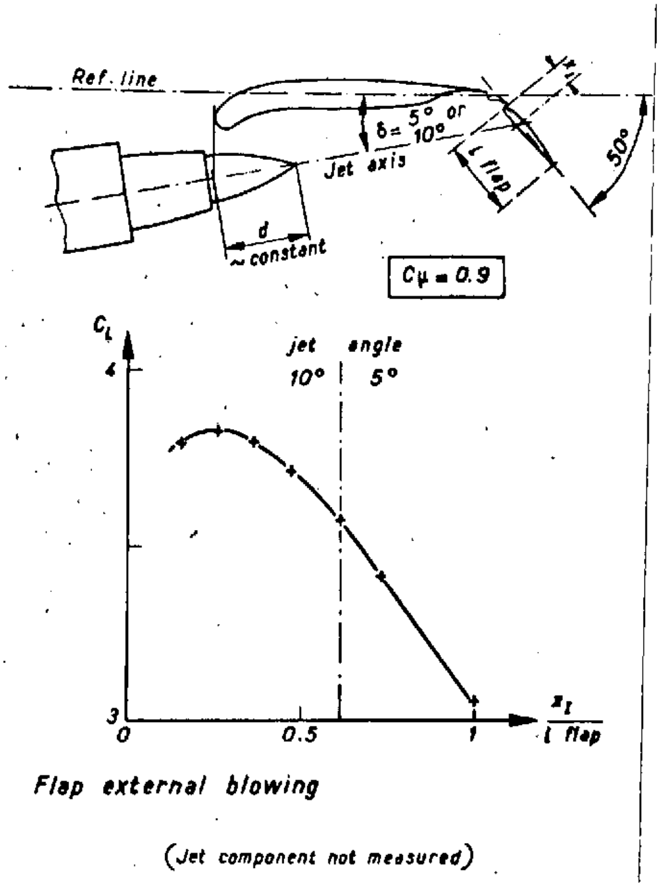



Figure 12. Influence of the jet impact position on the flap on the measured lift; S1 Cannes tests.

Two types of such profiles are planned. One is called the peak ("peaky") profile because of the supersonic velocity peak in the vicinity of the leading edge, which is followed by a very slow recompression and without any shocks. This type of research has been carried out by the N.P.L. (England) group of aerodynamicists under the direction of H. Pearcey.

The other type of profile is called "supercritical" in the American literature, even though both types are supercritical.

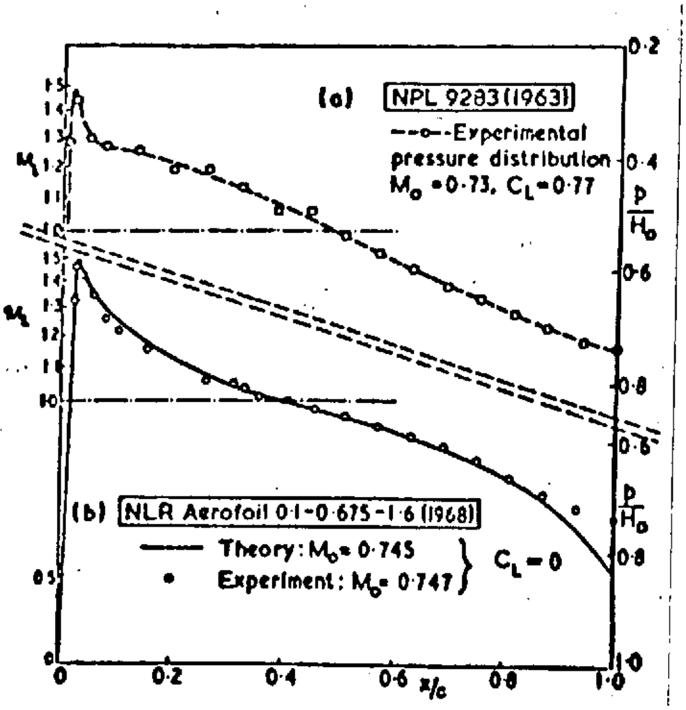



Figure 13. Supercritical flows without shocks: tests of the NPL (England) and of of the NRL (Holland).

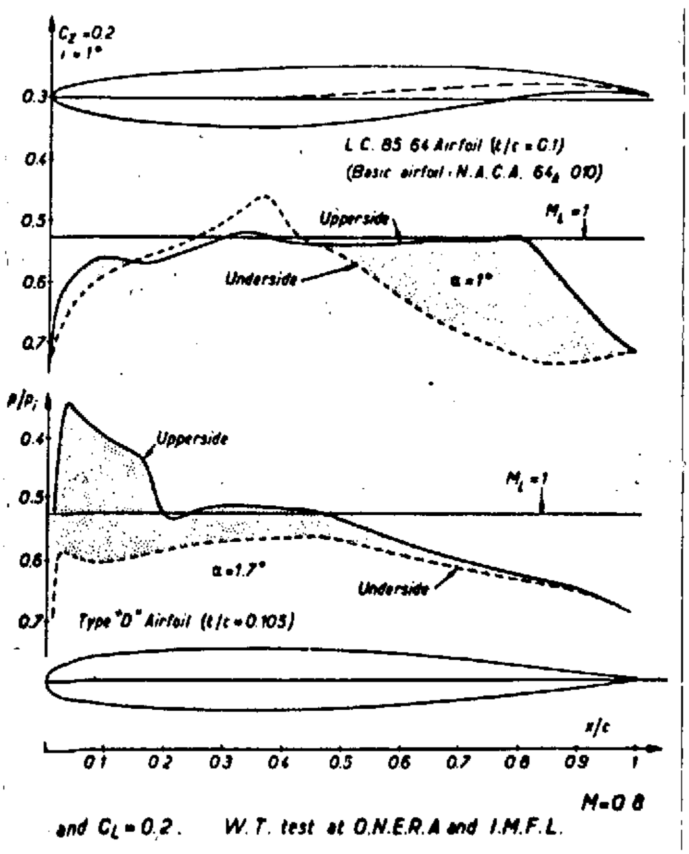



Figure 14. Supercritical profiles of the velocity peak type (peaky) or with a flat distribution (flat top); distributions of the pressures are compared, ONERA tests.

There is a flat bottom side over which the flow is supersonic, with very fast recompression. Sometimes there is a moderate shock along the rear part of the profile. Figure 4 compares the pressure distributions over two profiles of each type. The measurements were carried out at the O.N.E.R.A. for the same Mach number and for the same lift coefficient: $M = 0.8$, $C_z = 0.2$.

For the same flight conditions $(M, C_z)$, the two profiles have very different nose-down moments: The second type has a center of /52 pressure which is very far back (60% to 70%), compared with 25% for the "peak" type. This results in a corresponding relocation of the center of gravity during cruise for an STOL aircraft with straight wings or wings with a slight degree of sweepback and with a profile with a flat top surface. Consequently the flutter characteristics are of a very peculiar nature. This leads to important research for the future.

A discussion of a few theoretical difficulties involved in the calculation of supercritical profiles will be discussed in the appendix.

The problems discussed previously rarely lead to theoretical solutions. Consequently it is necessary to improve the wind tunnel test techniques.

Takeoff and landing

In order to carry out the study of configurations during takeoff and landing, it is necessary to have low velocity wind tunnels with the following features:

- microengines which will make it possible to correctly simulate the ejection velocities of large dilution engines;

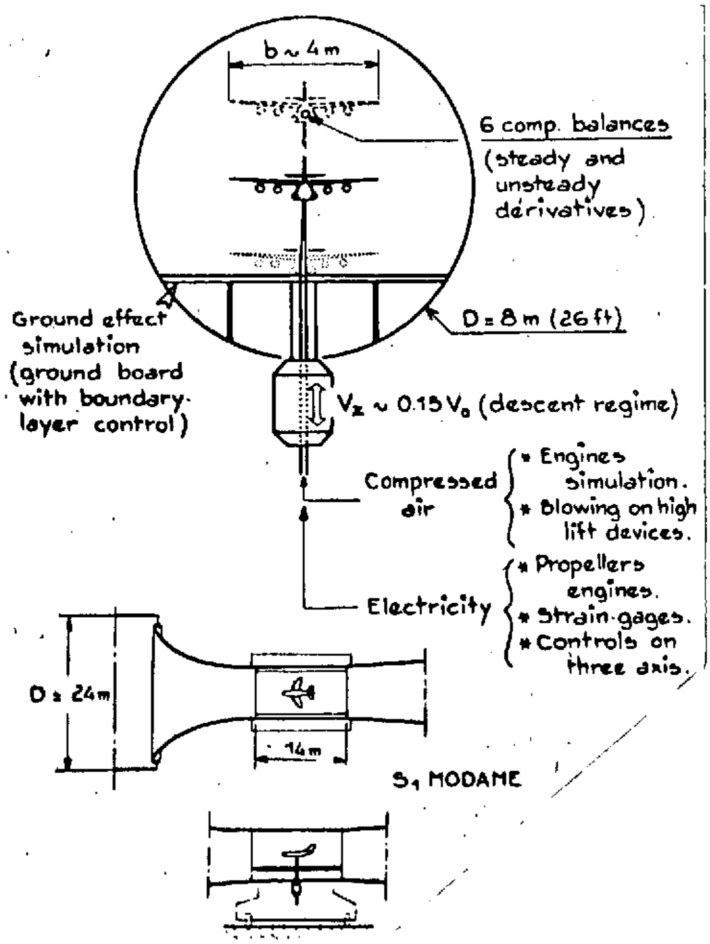



Figure 15. Installation for the landing and takeoff simulation in the S1 Modane wind tunnel.

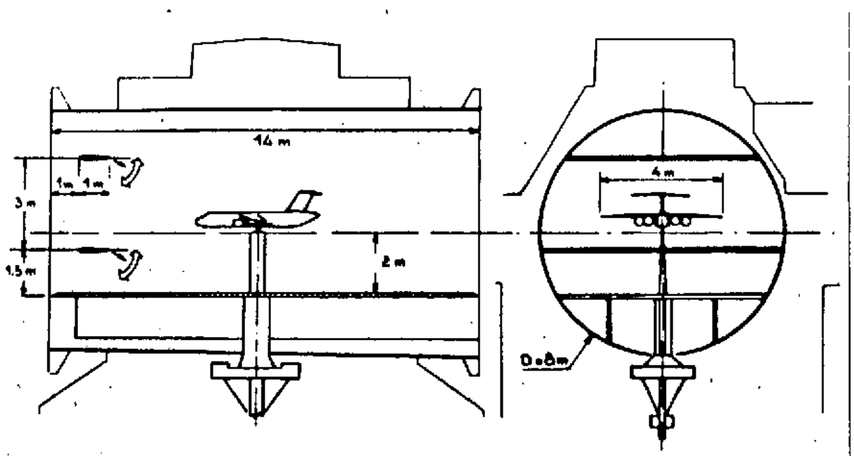



Figure 16. Installations for the simulation of gusts in the SI Modane wind tunnel.

- the wall corrections must be known for lift coefficients two or three times larger than conventional values of the past. Also devices must be available for preventing separation from the walls. Because of this, the tests must be carried out in larger installations;

- simulation of vertical and horizontal gusts.

Such systems are presently being built in several countries. Figure 15 shows installations developed for the sonic SIMA wind tunnel at Modane. The test section has a diameter of 8 meters and the velocities can vary between 0 and Mach 1. In this, an STOL model with a span of 4 meters will be subjected to all the classical tests for aerodynamic forces, the moments and their derivatives. In addition, it will be possible to simulate landing and take off conditions by displacing the support, with a vertical amplitude of 3.5 meters and a descent rate or ascent rate which is to scale. A special flap installation is placed upstream of the test section, as shown in Figure 16. It will then simulate the gusts to scale. Control of the diffuser is also provided in order to simulate longitudinal gusts. Finally, in order to avoid separations of the boundary layer on the ground, usually observed during high lift model test simulations, lower slots will be arranged as shown in Figure 17. /53

This series of improvements made to this wind tunnel will make it possible to carry out STOL tests beginning in 1974.

Cruise configuration

At the present time it is possible to carry out cruise configuration tests at a Mach number corresponding to cruise flight conditions, with local supersonic flow, but the Reynolds numbers are too small and there are significant differences between the

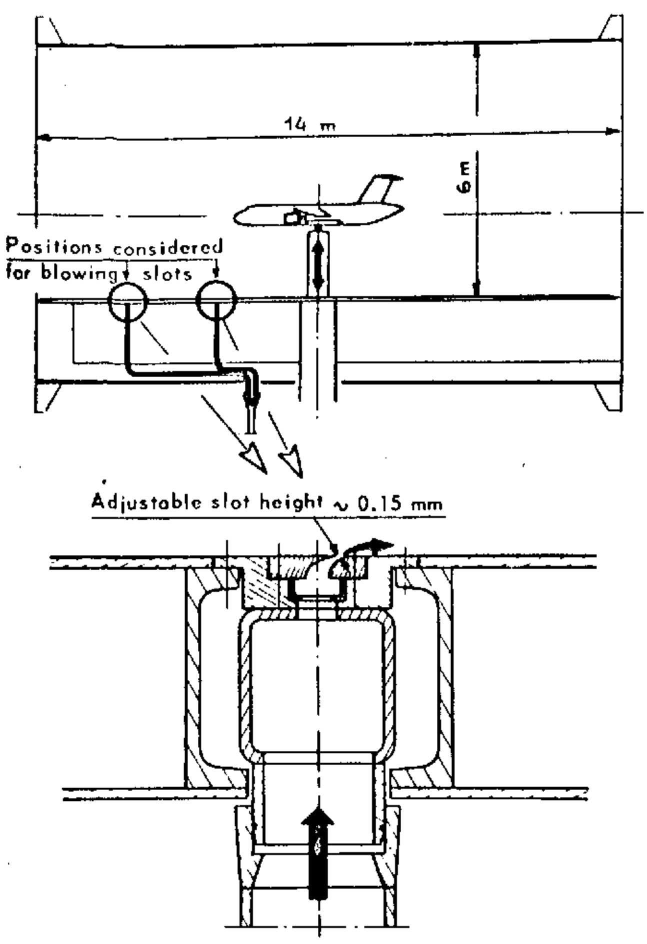



Figure 17. S1 Modane wind tunnel; blowing of the boundary layer from the ceiling for testing STOL aircraft.

nose-down moments observed in flight and measured in the wind tunnel. This was described in the publications (C5A, C141). This was attributed to a difference in the position of the shocks along the top side, which itself was caused by the incorrect simulation of turbulent boundary layers. The fact that the high Reynolds numbers could not be simulated for transonic conditions led to the formation of an international group of experts, called the "Ws group" (stands for Large Wind Tunnels).

This group will formulate specifications and requirements for new installations with large dimensions and which operates at high pressure levels (5 atmospheres, or greater). This will only be part of the solution because the models will be subjected to very large forces. For example, the model of a large modern jet engine with a span of 470 mm and tested at Mach 0.84, with a lift coefficient of 0.55, will produce a lift of 270 kg for

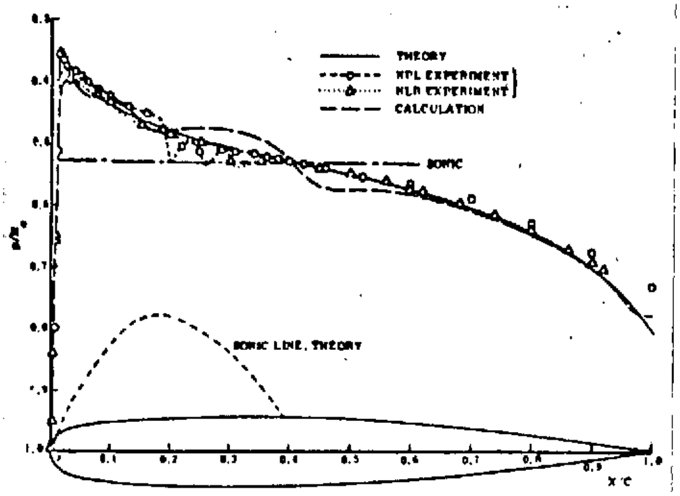



Figure 18. Supercritical profiles tested at the NRL (Holland); calculated and measured pressure distributions for zero incidence.

a generating pressure equal to 5 atmospheres. It is especially important to make sure that the model retains its shape and twist, especially in the supercritical range. It is particularly important to know exactly what profile is being tested for transonic velocities, where the velocity field depends very greatly on the local shape. This condition is even more strict for supercritical profiles being studied at the present time, because it has been found that small construction imperfections can be translated into large flow velocity field variations. New materials and new construction techniques, as well as new aerodynamic balances, will be necessary for carrying out the important measurements under these conditions.

Important fundamental results are also required regarding the question of wall corrections for permeable walls in transonic tunnels. In the past, experimenters limited the obstruction ratio, which is the ratio of the frontal area to the area of the test section, to values less than 1%. The velocity gradients produced in the test section by the small aspiration through the porous walls were deliberately assumed to be negligible. Transonic aircraft of the last 15 years were very tapered, with relative wing thicknesses of between 4 - 7%. /54

Today, things have changed completely. Two-dimensional wings with a relative thickness of 17% are at the present time being tested in transonic wind tunnels. The obstruction ratio can reach 5% and the aspired mass flux can reach 12%. This means that there is a high degree of uncertainty in representing such conditions. The old discussion about slots and holes and about their number, dimensions and inclinations will now give way to a strict investigation of the problems of the basic wall corrections and the appropriate limiting conditions.

Several teams are taking an active part in these important research projects. We will see enormous progress in this area in the next few years.

## Conclusion

In future years, the development of STOL aircraft will pose well-defined problems to the aerodynamicist. The research is interesting, difficult and progress will be made in many areas.

The widely accepted utility of this new type of aircraft will guarantee its success with the public. At the present time the resources are small but they are increasing. This project again shows that it is again necessary to completely integrate aerodynamicists in multidisciplinary teams, because propulsion, noise, aircraft regulations will greatly influence aerodynamic concepts. This will require new research and new equipment.

## Appendix

### Some comments regarding the difficulties of calculating transonic flows

It is impossible to give a quick treatment of the calculation of transonic flows, because this without doubt will be the object of much important research in future years.

A good presentation has been given by H. N. Pearcey [15]. The fundamental ideas which are the basis of the development of supercritical profiles without shocks are explained in a very clear way, such as has never been done before. He discusses the nature and intensity of the expansion and compression line network which characterizes the supersonic region of a profile. He also explains how the local curvature of the profile results from the difference between the angles made by these lines. Thus the flow will recompress without shocks if the compression and expansion waves in the supersonic region have an intensity such that they will cancel each other. The idea is therefore presented in a clear way, but the transfer to the calculation stage leads to various types of difficulties: theoretical difficulties, calculation difficulties and even financial difficulties.

A comparison of the various existing methods was made by Cole [16] in the case of a two-dimensional transonic flow. He discusses two hodographic methods for flows without shocks, and two methods in the physical plane for flows with shocks. A 5th method, which is a relaxation method using mixed type of equations, is discussed in more detail in the same article. This article is very dense and cannot be summarized, but it is possible to draw a few conclusions here.

As far as the direct hodographic method is concerned, one starts with the linearity of the equations for calculating particular solutions, and the desired form is derived. The case of non-zero lift is possible, but it is not as simple. However, the solution is given in terms of hypergeometric functions of higher orders. These are difficult to calculate and these are series with slow convergent properties. Even using a very powerful computer such as the Telefunken TR4, and using algorithms for accelerating convergence, it required 18 hours of machine time for establishing a function table up to order of 100. It then took 15 minutes to calculate a profile. The profile was given by coordinates and two derivatives at 40 points.

Another hodographic method was developed by Korn and uses /55 complex characteristics. This method required six minutes with a CDC 6600. The subsonic part, which determines the characteristics by means of 200 points, requires 20 seconds but the central memory must store 40,000 words of 60 bits at each. The supersonic region uses 400 points along each characteristic and takes two minutes for an accuracy of 4 digits.

The "function of time" method of Magnus and Yoshihara assumes isentropic flow. Figure 18 compares the flow without a shock calculated by such a method with that obtained by the NPL (circles) and at Amsterdam (triangles). One finds a waviness indicated by dashed lines which is caused by numerical factors, which indicates that there is a shock which is the result of an insufficient definition of the velocity peak at the tip. A non-zero lift case was calculated. This was for the profile NASA 64 A 410 at 4° of incidence. In this case, the

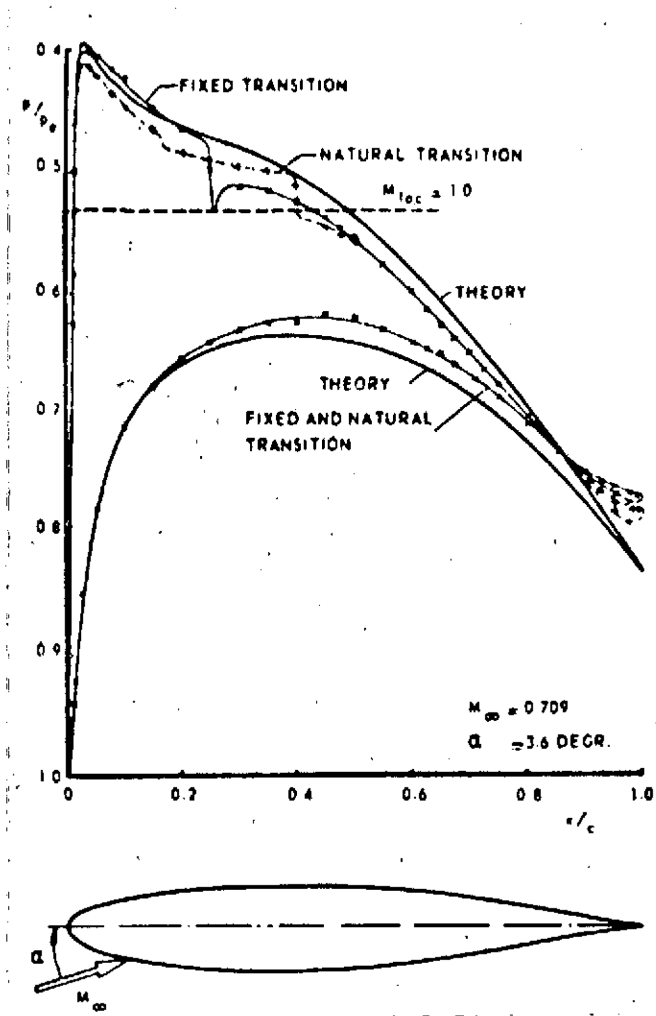



Figure 19. Supercritical profiles tested at the NRL (Holland); calculated and measured distributions for the incidence angle ($\alpha$ = 3.6°).

network involved 3700 points, and 530 calculation steps were necessary for convergence to a sufficiently stable result, that is, 2.2 hours on the CDC 6400.

The main feature of the problem is the large number of points required in the region of the leading edge. Cole published his own method based on a relaxation process. The method fails in the supersonic region, and a system of local differences is used, after testing whether the velocity is subsonic or supersonic. The method requires 30 minutes on a 360/44 and much less on a CDC 6600.

When one reads these comments, one has the impression that these calculation problems are quite delicate and the theoretical rigor is compromised in order to accelerate the convergence. When commenting on these methods, the author himself puts the word "solution" within quotation marks in an eloquent manner. An interesting remark was made by Boerstel at Amsterdam [17]. If Figure 19, which shows the calculation results of a supercritical pressure distribution at Mach 0.709 at 3.6°, is compared with the corresponding wind tunnel tests, there is a weak shock. On a strioscopic photograph, the shock is stable if the exposure time is 1/250 seconds, but a series of bursts separated by $10^{-8}$ seconds shows that there is a group of moving shocks! Recently Nieuwland [18] gave a brief but wide ranging summary of the development of transonic profiles without shocks.

A few of the calculated profiles or the empirically defined profiles are very sensitive to small variations in incidence or Mach number. In this area, just like in many other areas of aerodynamics, the best optimization will be a complicated compromise between peak performance and a regular response under non-nominal conditions. On the other hand, the difficulties encountered in the calculation of complex non-viscous flows will not hide the fact that the real flow is viscous, that stable physical solutions can exist, as empirical research has demonstrated. See Figure 13 of Pearcey.

At the present time, the theoretical work is devoted to the study of the external flow in the presence of the boundary layer.

## References

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1. Ville, G., Ph. Poisson-Quinton and E. Leygue, American Research and Projects of Aircraft which can Land and Take Off Vertically. Doc Air Espace, No. 94, September 1965 and No. 97, March 1966.

2. Poisson-Quinton, Ph. Introduction to VSTOL Aircraft Concepts and Categories. AGARD/V.K.I. Lecture Series No. 9, May, 1968.

3. Smith, J. T. Quiet Propulsion. Flight International, August 17, 1972.

4. Kovitch, J. Wol, C. W. Lambont and D. W. Lochtie. Fundamental Limitations on V/STOL Terminal Guidance Due to Aircraft Characteristics. NASA-CR-1901, December, 1971.

5. Schaffer and Velten. Operational Constraints for STOL Aircraft. AIAA Paper 70-1283 Houston, October 19-22, 1970.

6. Ransone, R. K. Proposed STOL Definition and Field Length Criteria. Journal of Aircraft, December, 1971, p. 971.

7. NASA. Vehicle Technology for Civil Aviation: the Seventies and Beyond. Langley Research Center, November, 1971. Supplement to NASA S.P. 292.

8. Bowling, H. T., C. H. Hurkamp and R. M. Thornton. Optimizing the Propulsion/Lift System for Turbofan STOL Aircraft. Journal of Aircraft, June, 1971.

9. Carrière, P., E. Eichelbrenner and Ph. Poisson-Quinton. Theoretical and Experimental Contribution to the Study of Controlling the Boundary Layer with Blowing. First Congress ICAS, Madrid, September, 1958.

10. Schlichting, H. Aerodynamic Problems of High Lift. Zeitschrift für Flugwissenschaften, Vol. 13, No. 1. January, 1965.

11. Aviation Week and Space Technology - NASA Building STOL Transports. A.W., September 13-19, 1971, p. 44.

12. Lowry, R. B. and G. S. Oates, Jr. Air Force STOL Tactical Transport Technology Program. Society of Automotive Engineers National Aeronautic and Space Engineering and Manufacturing Meeting. Los Angeles, September 28-30, 1971.

13. Whittley, D. C. The Aerodynamics of High Lift Illustrated by Augmentor. Wing Research. 12th Anglo-American Aeronautical Conference Calgary, July 7-9, 1971, Paper 72/20.

14. Quigley, H. C., S.R.M. Sinclair, T. C. Nark and J. V. O'Keefe. A Progress Report on the Development of an Augmentor Wing Jet STOL Research Aircraft. S.A.E. Paper 71-0757, September, 1971.

15. Pearcey and J. Osborne. Some Problems of Transonic Aerodynamics. Seventh ICAS Congress Rome, September, 1970, ICAS Paper No. 70-14.

16. Cole, J. D. Calculations of Transonic Flows. Seventh ICAS Congress Rome, September, 1970, ICAS Paper No. 70-12.

17. Boerstel, J. W. and B. M. Spee. Lifting Aerofoils with Supercritical Shockless Flow. Seventh ICAS Congress, Rome, September, 1970. ICAS Paper No. 70-15.

18. Nieuwland, G. Y. Choice and Balance; a Research Programm in Aerodynamics in Perspective. Eighth ICAS Congress, Amsterdam, September, 1970. ICAS Paper No. 72-01.

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16. Abstract

Some of the aerodynamic problems raised by the development of future S.T.O.L. aircraft are discussed. This discussion emphasizes three characteristic aspects of these aircraft:

- first, using the engine air flow to induce most of the lifting forces generated by the wing confers a new severity to the definition of the aircraft behavior in case of engine failure:
- second, the important circulation around the wing, the variations in angle of attack and sideslip due to gusts applied at low speed, subject the aircraft lifting surfaces to highly deflected flow configurations, at present very difficult to predict through calculation; this situation justifies in its turn the creation of new test facilities and calculation methods;
- lastly, a constraint relative to noise, recently made even more severe, is added to other design constraints to make more complex the economic optimation of projects, by the enforced rejection of solutions that are aerodynamically attractive but are intolerably noisy.

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